

Gas in the central region of AGNs: ISM and supermassive gaseous objects

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Abstract. This is a starting point of future work on a more detailed study of early evolutionary phases of galactic nuclei. We put into port the study of the evolution of star accretion onto a supermassive gaseous object in the central region of an active galactic nucleus, which was previously addressed semi-analytically. For this purpose, we use a gaseous model of relaxing dense stellar systems, whose equations are solved numerically. The model is shortly described and some first model calculations for the specific case of black hole mass growth in time are given. Similar concepts will be applied in future work for a system in which there is a dense interstellar medium as a possible progenitor of a black hole in the galactic centre.

1. Introduction

Several theoretical models have been proposed in order to explain the properties of quasars and other types of active galactic nuclei (AGN). In the 60's and 70's supermassive central objects (SMOs) were thought to be the main source of their characteristics (luminosities of $L \approx 10^{12} L_{\odot}$ produced on very small scales, jets etc). The release of gravitational binding energy by the accretion of material onto an SMO in the range of $10^7 - 10^9 M_{\odot}$ has been suggested to be the primary powerhouse (Lynden-Bell, 1969). Supermassive stars (SMSs) and supermassive black holes (SMBHs) are two possibilities to explain the nature of these SMOs, and the first may be an intermediate step towards the formation of the former type (Rees 1984). Large amounts of gas lost by stars during their evolution will stock in galactic centres, as have shown numerical studies of the evolution of gas in the bulge of spiral galaxies (Loose et al. 1982) and in elliptical (Loose and Fricke 1980, Kunze et al. 1987).

In previous work we addressed a semi-analytical study, revisiting and expanding classical paper's work, the classical problem of star accretion onto a supermassive central gaseous object in a galactic nucleus (Amaro-Seoane & Spurzem 2001). The resulting supermassive central gas-star object was assumed to be located at the centre of a dense stellar system for which we used a simplified model consisting of a Plummer model with an embedded density cusp using stellar point masses. From the number of stars belonging to the loss-cone, which plunge onto the central object on elongated orbits from outside, we estimated

the accretion rate taking into account a possible anisotropy of the surrounding stellar distribution.

This initial approximation to the real physical configuration was just a first probe of the complexity of the problem. We envisaged the problem from a static point of view. This allowed us to treat it in a semi-analytical way. Such a treatment is (of course) not realistic, but just a useful approach, for it gives us a nice and simple basic idea of what could be going on in such a particular scenario. In this paper we put into port the evolution of the static situation thanks to an anisotropic gaseous model. A next step will include the implementation of the small-scale fluctuations on the large-scale motion of the gas in order to study the transfer of momentum between the interstellar medium (ISM) and the system of stars. Just et al. (1986) derived an equation for the large-scale motion of the interstellar medium in the presence of small-scale fluctuations. Of particular interest is the study of the dynamical friction between the ISM and the system of stars, which includes the development of a friction term describing the momentum transfer between the interstellar gas and the stellar component.

2. The gaseous model

To go from stationary to dynamical models we use a gaseous model of star clusters (Lynden-Bell & Eggleton 1980, Bettwieser 1983, Heggie 1984) in its anisotropic version (Louis & Spurzem 1991, Spurzem 1994, Giersz & Spurzem 1994). It is based on the following basic assumptions:

- The system can be described by a one particle distribution function.
- The secular evolution is dominated by the cumulative effect of small angle deflections with small impact parameters (Fokker-Planck approximation, good for large N -particle systems).
- The effect of the two-body relaxation can be modelled by a local heat flux equation with an appropriately tailored conductivity.

The first assumption justifies a kinetic equation of the Boltzmann type with the inclusion of a collisional term of the Fokker-Planck (FP) type:

$$\frac{\partial f}{\partial t} + v_r \frac{\partial f}{\partial r} + \dot{v}_r \frac{\partial f}{\partial v_r} + \dot{v}_\theta \frac{\partial f}{\partial v_\theta} + \dot{v}_\phi \frac{\partial f}{\partial v_\phi} = \left(\frac{\delta f}{\delta t} \right)_{FP} \quad (1)$$

In spherical symmetry polar coordinates r, θ, ϕ are used and t denotes the time. The vector $\mathbf{v} = (v_i), i = r, \theta, \phi$ denotes the velocity in a local Cartesian coordinate system at the spatial point r, θ, ϕ . The distribution function f is a function of, $r, t, v_r, v_\theta^2 + v_\phi^2$ only due to spherical symmetry. By multiplication of the Fokker-Planck equation (1) with various powers of the velocity components we get up to second order a set of moment equations which is equivalent to gas-dynamical equations coupled with Poisson's equation: A mass equation, a continuity equation, an Euler equation (force), radial and tangential energy equations. The system of equations is closed by a phenomenological heat flux equation for the flux of radial and tangential r.m.s. kinetic energy, both in

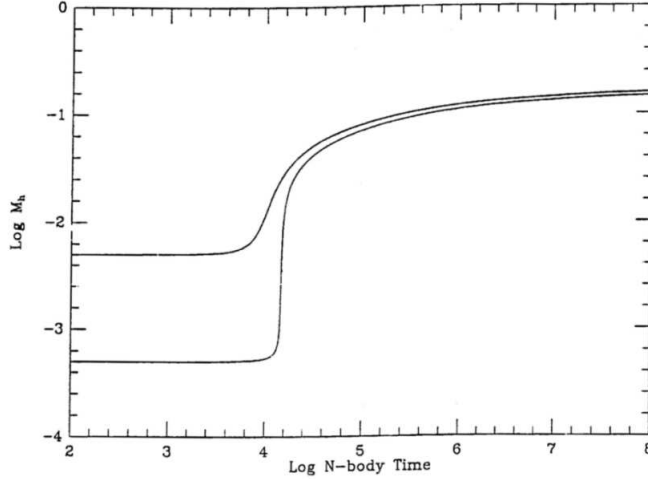


Figure 1. Central Black Hole mass in M_{\odot} as a function of time (1 time unit corresponds to $1.04 \cdot 10^{12}$ sec). The lower curve starts at a seed mass of 50, the upper at $500 M_{\odot}$, respectively.

radial direction. The concept is physically very similar to the original one of Lynden-Bell & Eggleton (1980). As a consequence we derive a set of dynamical evolution equations in spherical symmetry for our system which resemble very much standard gas dynamical equations. The reader interested in more details is referred to the above cited papers. A simple diffusion model is then used to describe the diffusion of stars into the loss cone and their subsequent accretion onto the black hole, which will be published soon (Amaro-Seoane & Spurzem, in preparation).

To solve our equations we discretise them on a logarithmic radial mesh with typically 200 mesh points, covering radial scales over eight orders of magnitude (e.g. from 100 pc down to 10^{-6} pc, which is enough to resolve the system down to the vicinity of a massive black hole's tidal disruption radius for stars. An implicit Newton-Raphson-Henyey iterative method is used to solve for the time evolution of our system.

As a sample, in Fig. 1 we follow the evolution of the mass of a black hole (BH) in an isolated star cluster of $10^5 M_{\odot}$ undergoing core collapse. We start with two initial masses for the BH's of 50 and 500 (normalised to the total cluster mass), the time unit in the figure is $1.04 \cdot 10^{12}$ sec. The central density increases until a maximum value at which the energy provided by the star accretion onto the black hole stops the collapse; the subsequent reexpansion of the cluster core halts the black hole growth. Independent of the initial seed black hole mass the final mass is very similar, which we consider as an effect of self-regulation due to the feedback of black hole growth to the cluster evolution.

Our results compare well with other studies using direct solutions of the Fokker-Planck equation or Monte Carlo models (Lightman & Shapiro 1977, Marchant & Shapiro 1980). Note that the Monte Carlo approach has been recently revisited and improved by Freitag & Benz (2001). In contrast to the other models the gaseous model is much more versatile to include all kinds of important other physical effects, such as the dynamics of gas liberated in nuclei by stellar evolution and collisions and its interaction with the stellar component (see for a preliminary study Langbein et al. 1990).

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